

2012

Encyclopedia of Mathematics and Society: 'Engineering Design'

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Bigelow, Kimberly Edginton, "Encyclopedia of Mathematics and Society: 'Engineering Design'" (2012). *Mechanical and Aerospace Engineering Faculty Publications*. 5.
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Engineering Design

Category: Architecture and Engineering.

Fields of Study: Algebra; Geometry; Measurement.

Summary: Engineering design is a carefully regulated process to create optimal solutions for given problems.

Engineers design everything from automobiles and bridges to prosthetic limbs and sporting equipment. Designing is different than simply building in that it requires the adherence to a very systematic, yet iterative, process known as the “engineering design process.” This process is to engineers what the scientific method is to scientists—guiding steps that help ensure that the end result is the best it can be. When a new product is created without following the steps of the engineering design process, there is a higher likelihood that the product designed will lack some important aspect: the end product may not appropriately account for the needs of its users, it may cost too much to manufacture, or it may not have been tested to ensure safety. Accordingly, the term “designing” refers to the entire process, such that an engineer “does design.” The use of the term “design” as a noun may be used at different points in the process but may have very different meanings depending on what phase of the process the engineer is in. Design may really mean “design idea” during the brainstorming phase of the process or “model or prototype of the design” during the building phase of the process.

The engineering design process requires the application of mathematics in many of the steps. Throughout the process, engineers use basic mathematics concepts, including addition and multiplication to calculate costs; geometry to calculate surface areas for material needs; and measurements to ensure appropriate dimensioning. However, more sophisticated projects may require the application of higher-level mathematics, such as calculus and differential equations, to solve the technical engineering problems certain designs pose.

The Engineering Design Process

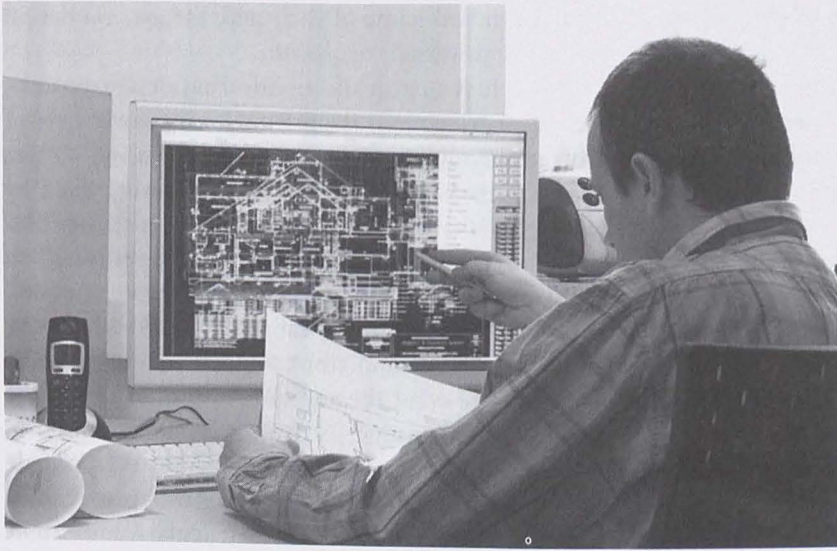
The engineering design process refers to the steps that are required to create the best possible solution to a problem. It is a process often undertaken by a team of engineers who work together, though it can be performed by an individual—trained or untrained as an engineer. Though there is no consensus as the exact

breakdown and name of each step, the general design process is universally accepted.

In the first step of the engineering design process, the engineering team is presented with some type of problem or unmet societal need to be solved. Often, this problem is presented to the engineering team by a company that is trying to offer a product that better meets its customers’ needs. The engineer must ask many questions to both the client and the user, as well as conduct background research, in an effort to establish the objectives and constraints of the design. The objectives are what the solution to the problem (the final designed product) should aim to accomplish. The constraints are the factors that limit the possible designs, such as time, money, or material restrictions. Time and money constraints are particularly important as they often drive the project and must be monitored throughout to ensure that the project is completed on time and within budget. At the end of this step of the design process, the engineering team fully understands the problem and has developed objectives and constraints to guide their possible solutions.

In the next step of the engineering design process, the engineers generate design ideas to solve the newly refined problem. Idea generation normally occurs through group brainstorming methods, with the goal of producing as many ideas as possible. There are a number of methods used to enhance the innovation and creativity of the ideas that come from the brainstorming session, including ensuring group diversity, drawing from existing stimulus and building off of each other’s ideas. In this step of the process, some of the generated ideas will evolve into rough hand-drawn sketches. These sketches need to show perspective and relative size clearly.

The next step of the engineering design process is design selection. A method known as “decision analysis” is most commonly used for design selection. Decision analysis is a systematic process to objectively and logically choose the best idea to move forward with from the many generated through brainstorming. It is important because it reduces the likelihood of a designer’s bias in selecting a design. As a first step, the brainstormed ideas must initially be narrowed down through discussion or other means to only the handful of ideas that appear to be most promising. These ideas are then compared through decision analysis. For the decision analysis, it is first necessary to create a list of design



Once the engineering team is satisfied with the final product, the design is executed through computer-aided design (CAD) drawings.

to be made. Determining these dimensions often requires in-depth estimation and calculation. At the most simplistic level, dimensioning requires taking into account any necessary clearances or gaps in the design, especially when multiple parts need to be fitted together. It may also be necessary to determine the combinations of dimensions that ensure a specified surface area requirement is met, in which case algebra can be helpful. More in-depth designs may require that dimensions come from established tables of normative dimensions, such as anthropometric tables, providing typical measurements of different-sized people, or from

engineering analysis, such as stress or buckling calculations. Deriving dimensions from engineering analysis methods often requires high-level mathematics and a technical background in engineering but ensures a stronger, safer product.

criteria and weight them based on their relative importance. As an example, as safety is paramount in design, the criteria of “safety” would be the most important criteria and would be weighted as 1.0 on a scale of 0–1. The criteria of “portability,” on the other hand, might be desirable but not necessary, so it would be weighted as 0.5. There is no standard as to what weighting scale should be used but it is important to be consistent in its application. For each criterion, in addition to the determined weighted importance, a numerical range must also be established for rating each design with respect to the criterion. When possible, this range should be as objective and quantifiable as possible.

Once the design has been refined and the dimensions are known, building begins. For most designs, a scale model or a simplified prototype is created first to test for feasibility of the design before further time and money is invested. To create a scale model, all dimensions of the detailed sketches must be reduced by multiplying by some chosen scaling factor, often 1:2. Regardless of whether a full-size design or scale model is used, it is necessary to calculate the amount of each material that needs to be purchased to build the design. This requires thought and calculation, in particular when multiple parts could be cut from one piece of wood, metal, or fabric. Often, surface area is calculated according to the part’s geometry to determine the total amount of material needed. Once material has been secured, building of the design can occur. Throughout building, it is essential to make careful measurements for all parts because almost all designs are made from multiple components that must fit together to function as one product. For example, if a piece of wood to be used for one leg of a chair is measured even $\frac{1}{4}$ inch shorter than the other legs, it will

Each design being considered is then “scored” using the range for each criterion. The score is then multiplied by the relative criteria weight for a total score for each criterion and for each design. The total scores for each criterion are then summed for each design. The summed scores can be used to compare multiple designs, with the one scoring the highest being the one most likely to be successful.

After identifying a design to move forward with, refinement of the design is necessary. This step includes determining dimensions and materials that will be used to construct the chosen design. Detailed sketches, often drawn from multiple perspectives, are created and include the dimensions of each part

likely mean the finished chair will rock and wobble, and the design will be undesirable.

As a next step in the engineering design process, the constructed design is experimentally tested to determine its performance. This step helps to identify design strengths and weaknesses, which can be used to make recommendations for future refinement of the product. The specific experimental test performed is determined by the type of product designed and the design objectives. Regardless of the type of test conducted, measurements are taken throughout the experiment to record some aspect of the design's performance. Often, multiple trials will be taken, generating many data points. The data obtained from these measurements are then used to draw conclusions about the success of the design. Statistical analysis may also be employed to further assist in the interpretation of the data.

Almost always, the data collected during testing will suggest that the design could perform better if refined in some way. As such, it is common for the engineering team to return to the building stage and then iteratively cycle between it and testing steps until satisfied. At times, it may also be necessary to return to earlier steps in the engineering design process. Once the team is satisfied with the final product, final documentation is prepared to explain the design and share it with others. This is often done through computer-aided design (CAD) drawings and written technical reports.

Further Reading

- Dym, Clive L. and Patrick Little. *Engineering Design: A Project Based Introduction*. Hoboken, NJ: John Wiley and Sons, 2009.
- Eide, Arvide, et al. *Introduction to Engineering Design and Problem Solving*. New York: McGraw-Hill, 2001.
- Pahl, Gerhard, et al. *Engineering Design: A Systematic Approach*. 3rd ed. New York: Springer, 2007.
- Pilloton, Emily. *Design Revolution: 100 Products That Empower People*. Los Angeles, CA: Metropolis Books, 2009.
- Ulrich, Karl, and Steven Eppinger. *Product Design and Development*. New York: McGraw-Hill/Irwin, 2007.

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Equations, Polar

Category: History and Development of Curricular Concepts.

Fields of Study: Algebra; Communication; Connections; Geometry; Representations.

Summary: Polar coordinate systems were developed in the seventeenth century and have numerous modern applications.

The polar coordinate system is a coordinate system for the plane in which each point is determined by a distance from a fixed point, called the “pole,” and an angle from a fixed direction, called the “polar axis.” In normal usage, the pole is analogous to the origin in the Cartesian coordinate system, named for René Descartes. Both polar and rectangular (Cartesian) coordinates require two bits of data to place a point in the plane. While the Cartesian coordinate system requires knowing and placing two chosen lines to serve as axes, polar coordinates requires knowing one fixed point and one fixed ray. This characteristic makes polar coordinates useful in navigation. Students in twenty-first-century high schools are introduced to polar coordinate systems and the topic is further developed in college mathematics and physics classrooms.

History

The concept of using an angle and a radius may be dated to the first millennium B.C.E. There are references to Hipparchus of Rhodes (c. second century B.C.E.) using a type of polar coordinates to establish the positions of the stars that he studied. Archimedes of Syracuse describes his namesake spiral in the book *On Spirals*, as where the distance from a given point depends on the angle from a given radius.

In a number of articles about the development of polar coordinates, most notably the 1952 article “Origin of Polar Coordinates” by Julian Lowell Coolidge, further development of polar coordinates was generated by studying the Archimedean spiral. According to Coolidge's history, the first mention should go to Bonaventura Cavalieri in his 1635 treatise *Geometria indivisibilibus continuorum* in which he studies the spiral of Archimedes. Cavalieri studies the area inside the spiral and relates it to other known areas.

Like all good stories in the history of mathematics, this assertion is not without disagreement. In 1647,

See Also: Bridges; Green Design; Problem Solving in Society; Robots.